Artistic creation and computer interactive multisensory simulation force feedback gesture transducers

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ACROE - ICA

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Introduction

The ACROE and the ICA laboratory are two associated institutions running a program of research, development, creation and pedagogy in the field of computer for music and animated image synthesis. ACROE was founded in 1976 by Claude Cadoz, Annie Luciani and Jean-Loup Florens, in the *Institut National Polytechnique* of Grenoble (INP-G) with the support of French Ministry of Culture. The ICA (Artistic Creation and Computer) was initially a team, belonging successively to the LCP (*Laboratoire de la Communication Parlée* - INP-G), from 1976 to 1985, to the LIFIA (*Informatique Fondamentale et Intelligence Artificielle* - IMAG), from 1985 to 1995, and to the CLIPS (*Communication Langagière et Interaction Personne-Système* - IMAG). Since 1999, ICA is itself a laboratory of INP-G. ICA is in charge of the scientific research part of the global program.

The team built up from 1976 with fundamental aims motivated by the computer entering in several fields of artistic creation. The deep mutation represented by the computer, regarding the technology history, required a new and fundamental analysis of the role of the material tools in artistic creation as well as the role of the computer itself as tool. New concepts and theories were necessary that cannot be simply deduced from the previous.

The following few points, from this time, determined the basic positioning of the group:

- The computer being essentially a universal tool for *representation*, founded on the concepts of information, symbolic operations, language, etc. cannot be envisaged as a simple extension of the previous tools and instruments founded on physical, mechanical, energetic processes.
- The creation process, in "instrumental" arts is supported by a hierarchy of tools and systems, from a physical level (the musical instrument for example), to a conceptual level (the musical theories for example). But even if the theoretical evolutions of esthetics can be at the origin of technical changing in the physical tools, the technology, at a moment of the history, determines fundamentally the range and the limits of the possibilities. So, the first level at which we must start, while there is a so deep change in technology, is the most elementary: the physical instrumental level.
- The physical instrumental interaction is *sensory-motor* and *multisensory*. Sensory-motor: every perception needs always a kind of action, and every action is always more or less accompanied by a perception. Multisensory: every perception, even through a specific channel, is always more or less correlated with perceptions on other channels.
- The computer, as a general representation system, must be used at a first stage for the level of the instrumental interaction. This level, then, will be the base for the development of the higher levels.

The computer was then envisaged to introduce explicitly a new mediation level in the creation process, through the paradigm of the interactive and multisensory simulation (IMS) of physical objects. This principle and its correlated techniques are the core of the computer creation tool envisaged. The higher level functionality being built from this base.

These points determined the general program axes:

- Research and development on the technical conditions for multi-sensory-motor interaction with computer: a substantial point here, is the concept and technology of force-feedback gesture transducers (TGR®, for *Transducteurs Gestuels Rétroactifs*, in French).
- Definition of a modeling and simulation language of physical objects - The CORDIS-ANIMA language.
- Designing and implementation of hardware and software architectures for real-time simulation - The TELLURIS platform.
- Study and research on the human interaction modalities, of the instrumental interaction, the instrumental gesture, the haptic perception and the multiple and multisensory action-perception loops.
- Research and development on the user interfaces for artistic (musical, animated images, multisensory) creation - The GENESIS and MIMESIS environments.
- Exploration, in scientific and artistic ways, of the universe of multisensory models of physical objects and phenomenon.
- Research and development on application of IMS and TGR in scientific and industrial fields.
- Application in artistic and pedagogic activities.

1. The force-feedback gesture transducers (TRG®)

To allow an instrumental gesture interaction with the computer, we have to take into account the fact that this interaction is bi-directional: from the human being to the computer, and conversely. The transducers, whatever their type (acoustic-electric, electro-acoustic, mechanic-electric or electro-mechanic, etc.) work, by their technologic principle, in a unidirectional way. So, the first characteristic of a gesture transducer able to support an instrumental interaction is that it must be, by principle, a pair of symmetrical unidirectional transducers: a force or a displacement sensor paired with an actuator (motor).

The physical phenomenon within the gesture action and perception (tactilo-proprio-kinesthesic perception) are complex and accurate. There are several important criterions that we must consider carefully in the design of retroactive gesture transducers:

- the number of degrees of freedom (DOF), (our hand has itself 23 degrees of freedom),
- the bandwidth of gestural signals (at least 1KHz),
- the resolution of displacements (up to 1μm),
- the range of forces (up to several hundred N),
- the range of displacements (at least ~ 1m).

One of the greatest difficulties in the design of such devices is to respect all these criterions at the same time in the same device assuming that under a sufficient level, the gesture interaction has no relevance at all.

And then, above all, a particular difficulty is to provide a well-adapted geometry (or *morphology*: shape and displacement trajectories,…) to the physical component we manipulate. Due to the physical contact and interaction, on the contrary to the electro- acoustical or visual transducers, it is not possible to build a universal mechanical architecture available for every application.

We worked on this set of problems since 1978. The first TGR was built by Jean-Loup Florens in 1978 [FLORENS (JL), 1978].

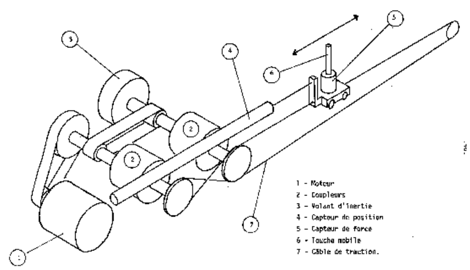


Fig.1a - On the left : First TGR® from ACROE - J-L. Florens (1978)

This device, sensing forces and displacements at its manipulation stick was able to produce a force-feedback of several tens of N with a time response of about 1ms, and with a displacement range of about 1m. It allowed for the first time to evaluate the importance of the force-feedback in the manipulation of simple virtual objects. It allowed also to highlight, from decisive experiences, the inter-sensory phenomenon and its importance (for example, the influence of the visual perception on a correlated tactile perception, and conversely).

A second device was built in 1981 by Claude Cadoz and Jean-Loup Florens [CADOZ (C), LUCIANI (A), FLORENS (JL), 1984, 1989], (fig.1).

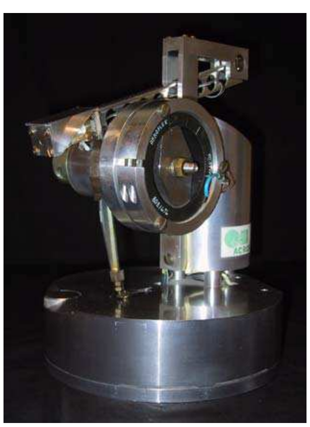


Fig. 1b : "la Touche", C. Cadoz, J-L. Florens (1981)

This piano key device, more compact and with better performances that the previous was the first table device. But it had always only one degree of freedom.

It allowed carrying out the first actual real-time multisensory interaction.

The next step was the invention of the concept and technology of *Modular Retroactive Keyboard* (CRM®) and of its associated principle of *Slice Motor*® [CADOZ (C), LISOWSKI (L), FLORENS (JL), 1987, 1989, 1990, NOUIRI (J), 1994, 1995], (fig.2).

This concept solved the two crucial problems within the TGR: modularity in terms of number of degrees of freedom, and modularity in terms of manipulation morphology.

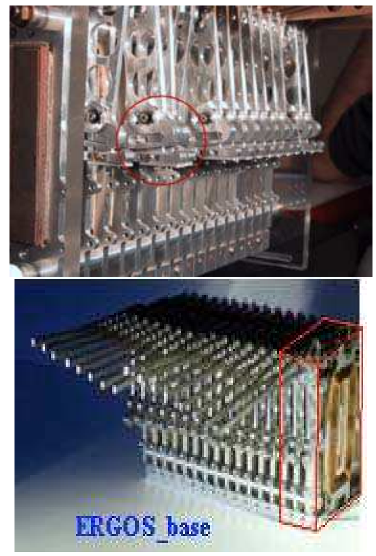
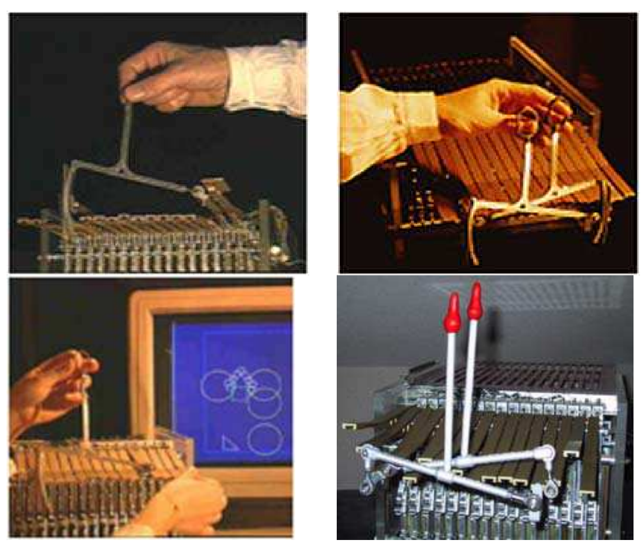


Fig.2 - The Slice Motor® - C. Cadoz, L. Lisowski, J-L. Florens, 1987

A unique rectilinear magnetic field is provided by a set of magnetic "slices" (one per key) inserted between flat coils (one per key) driving each key. This principle allows getting a strong magnetic field (by adding the one of each magnet) within a very compact volume. It is possible to add any number of keys in a complete modular way, according to the number of degrees of freedom needed.



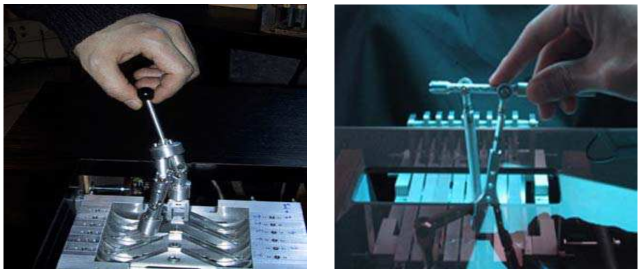


Fig.3 - Morphological modularity: several "*habillages*".

The "*habillages*" are added mechanical components, designed according to the specific applications, that convert the rectilinear and parallel sensor-actuator axes provided by the bloc to the manipulated object trajectories.
The first version (1987), with 16 DOF, 13,75mm width per slice, 3µm of minimum displacement detection, 80N of maximum force and 1ms of response time, was the most performant in its category. Thanks to this device, J-L. Florens [FLORENS (JL), 1988] achieved the first real-time simulation of a bowed string played with a real gesture, showing the fundamental role of the mechanical interaction between the player and the object in terms of quality and expressiveness of the sound.

Numerous other experiments achieved thanks to this equipment were decisive for the global understanding of the gesture in instrumental interaction and to demonstrate the relevance of physical modeling in this context.

After numerous analyses, experiments and improvements carried out from this period, a second family of TGR based on the same technology has been built. The maximum force provided on each DOF can reach today 200N, and the main categories of "*habillages*" have been designed and implemented: classical keyboard, 2D, 3D sticks, pliers, 6D stylet, 6D platform, 6D sphere,…
The size, variety and performances of the ACROE's TGR family give them the place of the best candidate for the future desk haptic devices.

These devices are today used for various applications: basic experiences on haptic modality in experimental psychology, telemanipulation, nanomanipulation, etc. and, of course for artistic musical, visual and multisensory creation.

2. The CORDIS-ANIMA language

The second important concept in the Interactive Multisensory Simulation is of course the simulation itself. So, the physical modeling, which is the background of simulation, is not simply a judicious paradigm to link with TGR, but the TGR and the physical modeling (or simulation of physical objects) are the two non-separable components of a single approach. Each of them can give the best when conceived and implemented within the context of the other. We considered these two concepts as non-separable from the beginning of our work in 1976.

The simulation paradigm holds the idea of a reference, for the mental and material representations, to the physical real objects and phenomenon. But it is only a reference, assuming that our active and cognitive system have been elaborated through permanent interaction with the real world. The laws, the regular properties of this last have equivalent and resonance in the structure and the economy of our active-cognitive system. This "ecological" point of view, related to the one of Gibson [GIBSON (J), 1979], is crucial in this approach. But it plays only as a reference since it is no longer question (and, by the way feasible) to duplicate the real world, but to provide a stable basis for invention of free imaginative and expressive representations.

Since the interaction between instrumentalist and instrument is supported, through the TGR, by two signals representing dual physical variables (intensive as input, extensive as output, or conversely), and in respect to the scale of the considered phenomenon, the conceptual framework will be the Newtonian physics. Then, the basic notions represented in the language will be inertia, spatial positions, displacements, velocities, and physical interaction laws, referenced to the classic mechanic mathematics.

Designing the simulation process, then, must be supported by a high level language avoiding the user to write the basic code for each case. The definition of the primitives is then determinant for the consistency, the generality and the relevance of the language. So, the CORDIS-ANIMA formalism [CADOZ (C), LUCIANI (A), FLORENS (JL), 1983, 1984, 1985, 1989, 1991, 1993, 1994] was completely (and exclusively) deduced from a main principle: the generalization of the interaction concept from the macroscopic scale (interaction between instrumentalist and instrument) to the components of the "object" themselves. This principle led to the general pattern of the CORDIS-ANIMA models: a network where the nodes (the <MAT> elements) are the smallest modules representing inertia, and where the links (the <LIA> elements) represent physical interactions between them. Under <MAT> is an algorithm calculating at each sampling time a position (in one, two or three-dimensional space) from a force input and according to an inertia parameter (M). Under <LIA> are several kinds of algorithms calculating the interaction forces between the two <MAT> it links, from their positions and according to basic interaction laws like elasticity, viscosity, etc.

These algorithms are designed in absolute optimized forms in regard of the number of basic numeric operations and of the calculation delays. So, the language is general and consistent.

This systemic pattern assumes that all the relations between its entities, whatever the scale (including the one of the instrumentalist itself) are bi-directional interactions. There is no *a priori* hierarchy, but any hierarchy can be decided in the modeling approach. The properties of the models are "emerging": they come exclusively from the local properties of its components and from the way they are combined in the network.

This is a strong choice having important consequences in the modeling approach and, more deeply, in the creation process itself, since we must think everything in terms of interaction.

3. Real-time simulators

The CORDIS-ANIMA system can be implemented on any general-purpose computer but the real-time interaction implies two major conditions: of course a maximum of computing power to simulate models of sufficient complexity, but also a specific control of the input and output protocols. A real-time simulation loop is indeed complex: it is constituted of three nested loops at three frequencies: the sound sampling frequency (the higher), the image sampling frequency and the gesture sampling frequency. The two last being a sous-multiple of the first. The synchronism must be absolute and driven by an external clock. For each input (gesture) data, the computer has to run a complete simulation loop including the nested ones and to produce the output data (for sound, image and force-feedback control).

In the early stages of development in the laboratory, the very first simulators were in fact real-time in their principle: an analogic computer has been used for the first force-feedback experiences, and a DEC LSI11 just after. The LSI11 processor was controlled by an external clock assuming a rigorous synchronism of the input and output. Of course, the simulated

models were very simple, and sometimes simulated in very low frequency, but they were real-time.
After that, we adopted two consecutive solutions for real-time simulation:

In 1982, Talin Berberyan [DARS-BERBERYAN (T), 1982, 1983] built a dedicated processor, the CTR (CORDIS Temps-réel), with a hardware implementation of the CORDIS-ANIMA algorithms, that was probably the first real-time processor for physical modeling. It allowed to simulate models of strings (or others) with about 20 to 30 masses in real-time and with gestural control. It has been replaced during the 80's by an Array Processor (AP120 from Floating-Point System inc.) that reach approximately the same performances, but with more generality.

In both of the previous cases, the simulator was a specific machine exclusively dedicated to simulation process and driven by a host computer. The next step was centered on Silicon Graphics workstations (1993) offering at this time the best compromise between the computing power, the graphical resources and the general software environment (under Unix). In this last case, as in any case today focused on any non dedicated platform, it is not possible to overcome the real-time constraints without intervention at the basic hardware (including the processor in a specific architecture allowing a complete control of the input/output data-flows) and at the basic software level (of the operating system itself in order to eliminate all operations not strictly involved in the simulation during the simulation process).

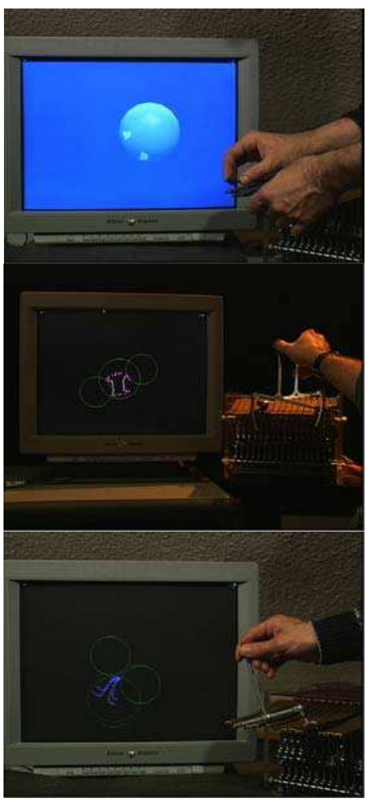


Fig.4 - Real-time manipulation with TELLURIS

The TELLURIS project, dedicated to real-time multisensory simulations with usual platforms, is at this time a major axe of development in the laboratory.

4. Study and research on the human interaction modalities

[CADOZ (C), LUCIANI (A), FLORENS (JL), 1984, 1988, 1992, 1994, 1996,1997]

The gesture, in instrumental interaction, is more than a simple "control". From a physical point of view, one can consider that during the interaction, the instrumentalist and the instrument are together a global system which properties depends intrinsically of the ones of each of them and which is more than the sum of their parts. Moreover, in the natural instrumental interactions, the instrumentalist is the source of any energy produced. From this point of view, the study of instrumental interaction concerns the physical phenomenon involved: the dynamic properties of the mechanical systems (of the instrument as of the instrumentalist itself), the energy transfers, energy transformations (from mechanical to acoustical vibrations or to visible movements).

From a communication point of view, the instrumental interaction is a combination of three nested loops, from the gesture action to the haptic perception, from the g.a. to the auditive perception, and from the g.a. to the visual perception. The study, then, concerns the human motricity, the auditive perception, the visual perception and the complex haptic perception (tactilo-proprio-kinesthetic perception). But even if these fields can be studied separately, the more relevant and needed study is about their combination in a global multi-sensori-motor process.

The study of the instrumental interaction, thanks to experimental devices or in order to develop them, suppose an investigation in each of these fields.

4.1 Instrumental gesture typology

[CADOZ (C), 1994, 1995, 1999]

The gestures applied on a same instrument may be of different types. But we can generally observe three main categories whatever the instrument and its function. They are determined by the principles of action, modification and selection.

In the action or *excitation* part of the gesture (for example what a violinist does with his right hand), we produce an energy, which is communicated to the instrument and converted by it into energy in the final phenomenon (the sound).

In *modification* or *modulation* part of the gesture (the left hand of violinist), we modify certain properties of the instrument, and, consequently the way in which it works in the previous function. We may spend energy in this gesture, but it is not transmit to the final phenomenon.

In the *selection* part of the gesture (ex: selection of keys in piano performance), we spend energy to move our fingers, hands, arms… in order to act on, or modify something but there is no actual effect on the instrument.

These three categories are generally intimately correlated. They are components of the gesture as a whole, but from a physical point of view, they correspond to different process and then, they are not supported by the same rules. From the communicational point of view, they don't play the same role. The *excitation* gesture has a quantitative consequence while the *modification* gesture is more qualitative. To the *selection* gesture corresponds an exploration of separate categorized elements.

One of the direct applications of this typology is that it offers criterions for gesture device design: the force feedback (which has a technological cost) is actually necessary only for the *excitation* gesture.

4.2 Coding, analyzing, composing the instrumental gesture

The gesture transducers introduced the *gesture signal*. So, in the same way than the *sound signal* gave rise to the Schaefferian "*Objet Sonore*", the gesture can become an *object* that can be recorded, observed, analyzed, transformed, edited, composed.

Unfortunately it is not so simple! The gesture interaction doesn't produce one, but two correlated (input and output) signals. Both of them can be recorded and candidate to editing. But what are the meaning and the consequences of the modifications we can apply on them? The output signal is completely determined by the input signal and the global transfer function of the virtual physical object. Conversely, the input signal is completely determined by the output (which is the input of instrumentalist) and the "instrumentalist transfer function", that is not a transfer function since the instrumentalist (hope so!) is an active component. So, too fast manners with this can be of catastrophic consequence: an arbitrary modification of one of the signals (*a fortiori* of the two) may be inconsistent within the integrity and permanence of the mechanical systems involved (instrument and instrumentalist).

This point represents the most important (and fascinating) question in this problem of understanding and treatment of instrumental gesture signal.

We laid down the basis and the theoretical solution of this problem. Assuming that the notion of gesture signal is, strictly speaking, non-definable, we replaced it by two concepts: the *gesture interaction signal*, which is solely measurable (through TGR) but that cannot express exactly the intention of the instrumentalist, and an hypothetical *internal gesture signal*, unreachable for measurement, that represents purely the gesture intention.

To define the second, Sylvie Gibet and Jean-Loup Florens [GIBET (S), FLORENS (JL), 1987, 1988] considered the instrumentalist itself as a two parts mechanical system: a purely passive one (that can be, incidentally, modeled thanks to CORDIS-ANIMA), and an ideal generator of force or displacement. Using the two interactive signals, it is possible (theoretically) to infer this model and to get the two separate parts. Editing the *internal gesture signal* so obtained, it becomes possible to create new gestures in respect of the consistence and integrity of the (virtual) instrumentalist.

This defines the rigorous theoretical context of coding, representing and editing of gesture. But it is quite complex to implement.

Some simplifications are possible when restricting to gestures with low interaction (for example in the percussive actions). Claude Cadoz and Christophe Ramstein [CADOZ (C), RAMSTEIN (C), 1990, 1991] developed a first gesture editor working solely on the input signal that allowed to create and edit *gestural scores*.

We are today working on further developments from these bases and for the definition of a standard format for the gesture representation, editing and transmission.

Through the instrument modeling, the gesture performance and the gesture editing, we have at our disposal the complete panoply to propose a new approach for music and animated images creation with computer, replacing totally the focus on the phenomenon by a focus on their causes. Of course, this approach is completely compatible with a continuation of signal modeling and editing and with composition of music and/or animated images scenarii by traditional methods.

4.3 Study of haptic modality and multisensory interaction

The technical equipment for gesture interaction (TGR) and interactive multisensory simulation (IMS) is, apart its application in music and image creation, ideal as experimental environment to study the human active-cognitive features.

Numerous experiments achieved randomly during the development and adjustment of the systems has soon focussed our attention on the peculiar properties of the cognitive system in interactive and multisensory situation: the role of the action during perception, the mutual influence of the sensory channels between them, or the robustness of our action-cognition system in certain cases, in spite of strong anamorphosis in the experimental conditions.

Some of these experiences have been carried out systematically in several specific works.

Sensory-motor anamorphosis - the "presence" notion

During the 80's, an important evolution occurred in the Man-Machine-Interaction domain (MMI), with concepts like direct manipulation of windows, icon, and menu through pointing devices (WIMP). This evolution from a technocentric to an anthropocentric approach of MMI borne the general idea of "metaphorisation" of interaction: make the manipulation of numerical entities and processes analogous to the manipulation of simple current objects. The full outcome of this concept is probably in the Virtual Reality trend, strongly emphasized from the end of 80's [RHEINGOLG (H), 1991, KALAWSKY (R-S), 1993, QUEAU (P), 1993, CADOZ (C), 1994, KUNII (TL), LUCIANI (A), 1998] in which the laboratory has been implicated.

A specific difficulty in this domain is to get a good projection of the real or referenced scene in the virtual ones. Two obstacles arise: a reduction of the properties through the numerical representation, and several kinds of anamorphoses between the real and the virtual scenes. We dedicated some works to the second [BOUZOUITA(A), CADOZ(C), UHL (C), LUCIANI (A), 1995, 1996, 1997].

An example of first order anamorphose (purely geometric) is, for example, when we control the 2D displacements of a point on a surface by two buttons driving separately the horizontal and the vertical dimensions. Such situations may be imposed by unavoidable technologic constraints, and sometimes they can be overcome by training. But in certain cases, they may bring advantages by transposing complex manipulation in simpler ones, better adapted to our possibilities or relieved of unnecessary and perturbing features. The question is then: on what criterion can we determine if an unavoidable anamorphose is a drawback, or how can we define an anamorphose that improve the interaction? This problem cannot be studied without considering the whole context of the interaction, and, particularly in terms of multisensoriality.

So, we brought to the fore, against the general expectation that gave favor to the immersive realism, that under certain conditions, we are able to tolerate quite strong geometrical and spatial anamorphoses, for example the separation and the delocalisation of the sources of the acoustical, visual and haptic phenomenon for a same virtual object, or the transformation of the range and trajectories of its manipulated parts. More precisely, when the force-feedback devices performances are sufficient and can respect the dynamic and energetic consistence, this last is more important than the pure geometric and visual one in the sophisticated (and costly) 3D immersive systems.

Now, this is crucial, because it is quite impossible to get relevant performances in force-feedback within immersive approach. On the other hand, these performances are possible in the desk and "*vis-à-vis*" systems.

In fact, the relevant and crucial concept here, is not this notion of purely visual and superficial realism, but the "feeling of presence": what makes us convinced that the phenomenon with which or by which we act and perceive are manifestation of reality? What makes present the things? Feeling of presence is stronger than "realism": it is more efficient, as well in learning tasks as in dexterous manipulation ones. Our hypothesis [LUCIANI (A)] is that the gesture channel, by its double function (linking closely action and perception) has the major role in this question: everything being equal elsewhere, just adding the gesture channel with sufficient performance brings a gap in the presence feeling.

The haptic and multisensory modality

In collaboration with the Experimental Psychology Laboratory (LPE) of the Université Pierre Mendès-France, in Grenoble, we worked to better understand the haptic modality and the gestural action-perception loop, and also to get a new understanding of the eye-hand inter-sensory coupling.

Some relevant results have been obtained recently: it seams possible to experimentally determine if a person acts preferably with reference to visual or to tactilo-propri-kinesthetic information,the person uses the forces he produces to get information on the external environment, certain forces perturb this estimation; so, there are useful and non-useful forces and certain persons are more sensible to this perturbation.

This results in new analysis methods allowing to better distinguishing between categories of people ("geometric people" and "dynamical people").

5. Environments and interfaces for artistic creation

The Gesture Interfaces (TGR), the simulation language (CORDIS-ANIMA), the simulator (TELLURIS) are the core of the creation tool. To complete this tool, a global environment to support the creation process must be designed.

The creation process is the series of operations we do in order to achieve an artistic work: a sound or/and a video record, a mixed numeric piece where gesture intervenes during the performance, a mixed piece where fixed numeric data, real-time numeric processes, real people, instruments, objects can perform together.

A creation environment must support the different tasks involved to achieve such works. It must be a production tool allowing to create the various objects: models, set of parameters, descriptions or recordings of real or virtual performances, sound and/or visual signals, scores, etc. But it must be also a *creation* tool, providing tutorials, supporting experimentation, suggesting heuristics, accompanying empiric explorations, allowing scribing and mnemonic marking. He must also provide tools to analyze and understand the phenomenon.

In 1985, Annie Luciani and Aimé Razafindrakoto [LUCIANI (A), 1985, RAZAFINDRAKOTO (A), 1996] designed the first modeler allowing to create graphically CORDIS-ANIMA models of 2D and 3D objects. The graphical interface was implemented in an Evans § Sutherland graphic workstation, and the models were simulated, for some of them in real-time, in the AP120 array-processor.

From the beginning of 90's, this area become an important part of our work. Because the real-time simulation techniques were at this time difficult to implement in ordinary platforms, we decided to develop a special effort in specialized interfaces dedicated to our physical modeling method. Moreover, we decided to approach independently the musical and the visual domains, which communities and needs were quite different. De facto, we are working actually and yet today on three environments: GENESIS for musical creation, MIMESIS for animated images creation (which are both non-real-time environments) and TELLURIS, which, connected with the previous, allows experiments and creation solely in the laboratory.

GENESIS and MIMESIS are both interfaces to built physical models within the CORDIS-ANIMA formalism. They work mainly in the same way, with a two modes process: creating and editing the models / running the models to produce the output phenomenon (sound signals / visual signal). Nevertheless, an important difference is that MIMESIS requires two steps in the final result production (see after).

GENESIS[1]

The creation of a model in GENESIS is made by direct manipulation of icons corresponding to the basic components (<MAT>, <LIA>) of the CORDIS-ANIMA language. Among them, GENESIS uses only the unidimensional components that are simpler to manipulate and to calculate, and that are sufficient. Positioning each <MAT> and linking then by <LIA>, on a workbench, we define the network (structure) of the objet. Then, we can give parameters and initial conditions thanks to suitable windows. A first simulation with a visualization of the movements of the objects at low rate allows verifying and understanding how the model works. Putting "microphones" on certain <MAT> elements, the movements of these <MAT> are recorded in a file that becomes the output sound files.

With these very simple bases, any user (even without any previous experience or specific knowledge) can get start with the concepts and functions, obtain models that works and understand the philosophy of the approach.

Beyond this elementary layer, numerous elaborated functions supported by very studied ergonomics allow to work at different levels: analysis of the properties of the structures, grouping of elements in functional entities, define macro and metaparameters allowing to control the "emergent" properties of the models, define the energy and action time of "pilot events", etc. Within these resources, GENESIS can be used not only to create sounds, but also to compose music in a new way (see below).

A wide and structured library of generic objects and processes is provided, accompanied with several kinds of didactic interactive supports.

The first version of GENESIS was distributed under partnership collaboration in 1996. From this date, numerous improvements made by Nicolas Castagné [CASTAGNE (N), CADOZ (C), 2002] and under a close collaboration with the users allowed to realize a very powerful tool. It is, with MIMESIS, the core of a user network created in 1998 in the Rhône-Alpes Region (France), and with several European institutions, called R_APM (Pedagogic Mobile Workshop Network).

MIMESIS

Apart the final object, which is an animated sequence instead of a sound file, MIMESIS, presents three other important differences:

[1] [See on www-acroe.imag.fr]

- the objects are 3D
- a textual language is used to create and edit the models
- a specific visualization phase is defined after the mechanical simulation.

Textuel langage

Due to the great number of particles and the complexity of the topology for the objects to be animated and visualized, a direct manipulation system is not possible. So it was necessary to define a language for the conception of such physical networks using logic operations, loops and symbolic assemblage under graphico-textual modalities.

Visualisation

As a strong feature of the simulation approach, the animated image creation works in the opposite way of the classical approaches. In the last, the visual properties of the objects (shape, texture, color, etc.) are first defined. Then, they are animated. In the MIMESIS (simulation) way, the movement (animation) is first, and then, the objects (a set of consistently moving particles) must be "clothed" with visual attributes. This visualization can be done through several different ways that are, in so speaking, a modeling of "how photons meet matter".

Annie Luciani and Arash Habibi [HABIBI (A), LUCIANI (A), 1993, 1997] developed a physical modeling based concept for visualization, the "engraved screen" inspired from the technique invented, in the traditional animated images domain, by Alexeieff.

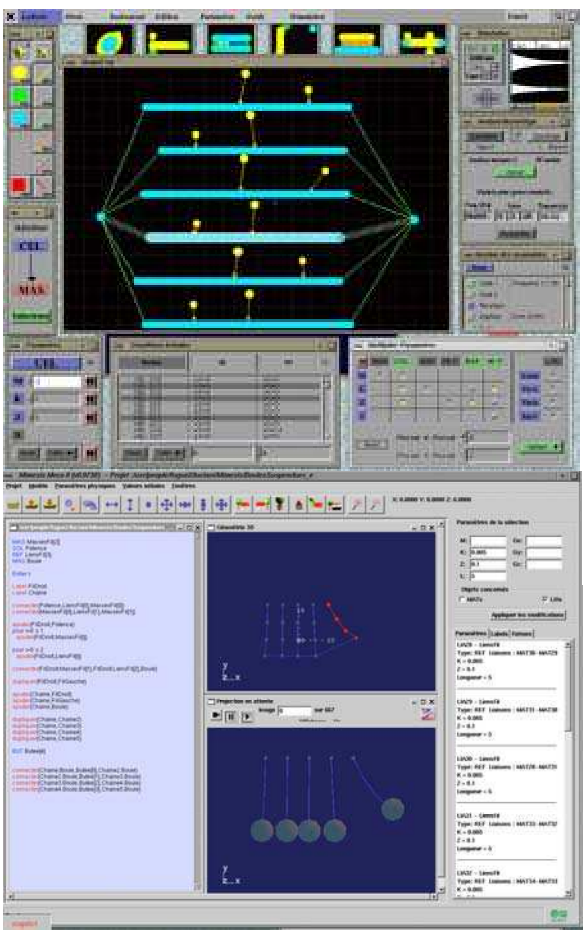


Fig.5 - The GENESIS (top) and MIMESIS workbenchs (bottom)

GENESIS and MIMESIS are used today in several cultural institutions and have been used also for numerous creations in music and image (see below). Claude Cadoz created is musical piece "*pico..TERA*" (2001) which uses exclusively GENESIS, and Annie Luciani her film "*Mémoires Vives*" (2001) that uses also exclusively the simulation technique.

6. The future platform

Sight and hearing are two complementary ways of apprehension of the objects and phenomenon in our environment. They inform us on different features from a same object or event. Some objects are better perceived by sight, other by hearing. So, it is not surprising that the creation of acoustic and the creation of visual phenomenon refer to different approaches. So, it was legitimate to dedicate tools for each domain. But the simulation paradigm is, precisely, above the perception modalities. Focusing on the causes rather than on their effects open the way for a deep synthesis allowing not only to superficially "paste" together the audio and the visual media, but to integrate a multisensory consistence in the "model" itself.

In an other hand, several years of development and practice within GENESIS and MIMESIS reveal two facts: numerous of their functionality are de facto formally identical (even if they are sometimes implemented with some superficial differences), and it is no rare that, using one or the other, the artists from one category develop obviously implicit thinking of the other. This incites strongly to actualize this synthesis in a unique tool.

The computing power needed by real-time multisensory simulation is today reachable, at least for models of reasonable complexity, and the CORDIS-ANIMA simulation process are now stable enough to be implemented in any platform.

If we add the fact that gesture devices (TGR) are now compact enough, with high-performance, to be integrate nearby the mouse on usual desk workstations, we can clearly conceive the future platform: a real-time simulator connected to a general physical modeler and to panoply of TGR.

Assuming (through a deep and carefully studied definition of the standards) the complete transparency and compatibility with general environments for computer artistic creation, and thanks to a relevant analyze of what can be transmit and what must be resident on a site, such platforms can be the nodes of a wide user network.

7. Artistic, scientific, research, creation and applications

In this last part, we expose and summarize, in a global survey, several significant steps in the research and application of these concepts and techniques, as well in the internal activities during or in parallel of the designing of the tools, as in collaborative activities in several fields: artistic creation, education and pedagogy, scientific and industrial applications.

<u>1979:</u>

- First TGR (J-L. Florens) and first experiments of gestural interaction with virtual objects (rigid obstacles), with an analogic calculator, and then with DEC-LSI11.
- First simulation of vibrating structures (C. Cadoz).

<u>1980-83:</u>

- First CORDIS-ANIMA simulator (C. Cadoz) on DEC-LSI11, first non real-time simulation of strings, and also the "falling ball", a simple model of a ball falling on the ground and producing very realistic sounds.

- First simulation of simple deformable objects manipulated in real-time and visualized on oscilloscope screen (A. Luciani).
- The "Touche" (C. Cadoz and J-L. Florens), simulation of various matter tactile rendering.
- The CTR (Cordis Temps-Réel), first physical modeling real-time procesor (T. Berberyan).
- Thanks to the CTR (specialized hardware for CORDIS-ANIMA simulation in real-time), simulation of plucked strings manipulated with the "Touche" and modulated (in elasticity) with a position sensor.
- Multisensory (eye-hand) experiences with simple visualization on oscilloscope screen.

<u>1983-87:</u>
- Implementation of real-time simulator on Floating-Point System AP120 (J-L. Florens).
- Implementation of the first modeler (A. Luciani, A. Razafindrakoto).
- Design of a vectorial real-time visualization screen (B. Merlier).
- Model of a marionette simulated and manipulated (by its feet) in real-time.
- First complete multisensory real-time simulation: a tennis ball (deformable object), played with a racket moving horizontally and manipulated with the "Touche", striking walls with acoustical vibrating properties.
- First models of bow-string interaction within the CORDIS-ANIMA modeling (C. Cadoz).
- Design of the "Clavier Rétroactif Modulaire" (CRM®) and its slice-motor technology (C. Cadoz, L. Lisowski, J-L. Florens)

<u>1987-93:</u>
- Thanks to the CRM and the AP120, first real-time simulation of a violin bowed string (J-L. Florens): the bow, handily manipulated through a joystick mounted on the CRM could be controlled on pressure and velocity. The bow-string interaction included the pressure parameter. A third key from the CRM allowed modifying the elasticity of the string, and then its pitch.
- With the same equipment, model of maracas with a set of particles in a box, manipulated in real-time with the CRM (C. Cadoz).
- Series of models of structured deformable objects for image animation (S. Jimenez, A. Luciani):
  - second model of marionette with force-feedback,
  - flag, football ball, trampoline, basketball basket, bicycle, complex vehicle, etc.
- First models (animated images) of non-structured objects: large set of particles in elastic interaction, producing waterfall effect, study of plasticity, etc. (S. Jimenez).
- Second model of complete real-time multisensory simulation, the "Granule" (J-L. Florens). This model was decisive in regard of the "presence" sensation: several small objects are enclosed in a circular 2D box manipulated by CRM. Thanks to a very precise modeling of the collisions between the objects and the container, even with very simple sounds and visual representations, but thanks to the deep consistence of the physical phenomenon and their relation to manipulation, we obtain a genuine effect of real existence ("presence").
- Development of the first gesture editor (C. Cadoz, Ch. Ramstein).
- Premises of GENESIS.

<u>1993-2000:</u>
- Implementation of simulator and all environments on Silicon Graphics Workstations, replacing the AP120.
- Models of complex structured objects and complex interactions: complex vehicle interacting with a soil (B. Chanclou). In the context of contracts with CEA for the studies of a VAP (Autonomous Planetary Vehicle), a complete 6 wheel articulated vehicle has been modeled, taking account the deformations of the wheels, their interaction with the soil, the deformation of the soil. This vehicle included also a physical model of motor generating its movements.
- In the same context, models of motricity have been studied and implemented in simple models of frog, snakes, etc.
- At the same time, B. Chanclou implemented the first physical models to realize non-physical operations: task planning for robotic application.
- Experiments on psycho-physics: using of multisensory simulation and gesture control in complex manipulation with several collaborating people on a same task (A. Bouzouita, C. Uhl).
- Models of collective behavior within large ensemble of particles:
  - models of sand, pastes, smoke, fluid (A. Luciani, Z. Junedi, A. Vapillon),
  - models of turbulence and chaotic phenomenon, autosimilarity,
  - application to the human scale of crowd behavior (A. Luciani, N. Tixier),

From these steps, the modeling activity in animated image made a breakthrough where the artistic (or esthetic) finality become significantly a guideline for modeling.

- Starting of the general study of the form/movement relation as a central paradigm in animated images with physical modeling (A. Luciani).
- Development of the "engraved screen" principle for visualization of physical model by physical models (A. Habibi, A. Luciani).
- Models of large scale atmospheric phenomenon: aurora borealis (E. Juliax, A. Luciani).
- First piece (image and music) created with the technique of ACROE, by ACROE: *ESQUISSES* - 1993. (ACROE).
- First versions of GENESIS and MIMESIS (1995, C. Cadoz, O. Corbun, A. Luciani, A. Habibi).
- First international Workshops with GENESIS and MIMESIS (1996).
- Starting of the R_APM project (Network of Mobile Pedagogic Workshop) in the Rhône-Alpes Region, and of teaching of artistic creation with computer by ACROE in several institutions (conservatory and school of art in Grenoble, Turin, Karlsurhe,…).
- Residences of artists in ACROE, creation of several musical and/or visual pieces by tens of artists, organization of public events (concerts, expositions, conferences).

<u>2000-2003:</u>
- Development of high level versions of GENESIS and MIMESIS and of their didactic environments (N. Castagné, C. Cadoz, A. Luciani, P. Fourcade).
- New TGR improving the performance of the CRM technology, and development of a complete panoply of "habillages": keyboard, 2D, 3D, 6D joysticks, etc. (J-L. Florens, G. Brocard).
- Development of the TELLURIS simulator on powerful multi-processor platforms (J-L. Florens, D. Muniz, Y. Chara).

- Development of fundamental experiments in haptic perception and multisensory interaction (A. Luciani, P. Ostorero, T. Olhmann).
- Development of scientific and technologic applications of the IMS and TGR:
  - introduction of the TGR in car industry (J-L. Florens, A. Luciani)
  - development of a "nanomanipulator with force-feedback" in collaboration with the LEPES laboratory (CNRS-Grenoble) (J-L. Florens, A. Luciani, C. Cadoz, J. Chevrier, S. Marlière, D. Urma).
- Development of new models: a new version of the bowed-string has been developed by J-L; Florens (invited conference in the Forum Acousticum 2002) where two strings can be played in a 2D space allowing to apply the bow on a realistic way on the both, or on one of them, with a very accurate gesture.
- First musical piece created by C. Cadoz ("pico..TERA") illustrating the principle of creation at the compositional structure level by the physical model paradigm.
- "Mémoires-Vives", film from A. Luciani.
- Development of wide structured libraries of models for musical creation and of the basis of the composition by physical modeling (C. Cadoz).

[see Figures 5X, 5Y, 6 and 7 at the end]

7. The team

Jean-Claude Risset is President of ACROE, and Max Mathews President of Honor, Annie Luciani and Claude Cadoz manage ACROE-ICA, Jean-Loup Florens has general scientific and technical high responsibility, Maria Guglielmi is Secretary of ACROE, Guy Diard was our so kind multimedia engineer that left us so suddenly in 2001, Nicolas Castagné joints us as permanent member just after his PhD.

Numerous non-permanent members working during periods on the different axes complete this basic team. More than 20 Univeritary Thesis have been written on the ACROE-ICA program. About 300 trainee students have worked on different subjects during the 20 last years. The list of names of these numerous contributors of the results we can show today is too long to be placed there. But we address them warm thanks.

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- General Council of Isère
- Culture dept. of Grenoble

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- Renault-United Parts France.
- CNRS (Force-feedback Nanomanipulateur Project), etc.

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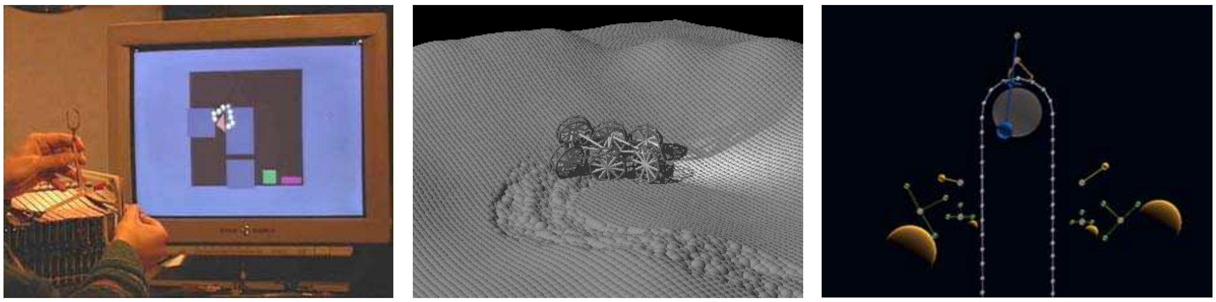

Figure 5X

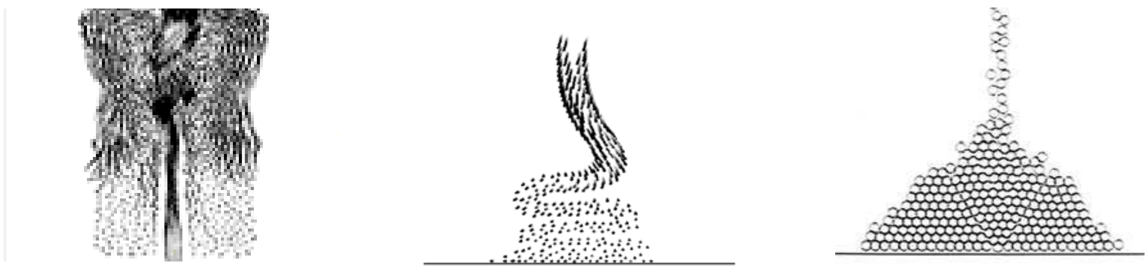

Figure 5Y

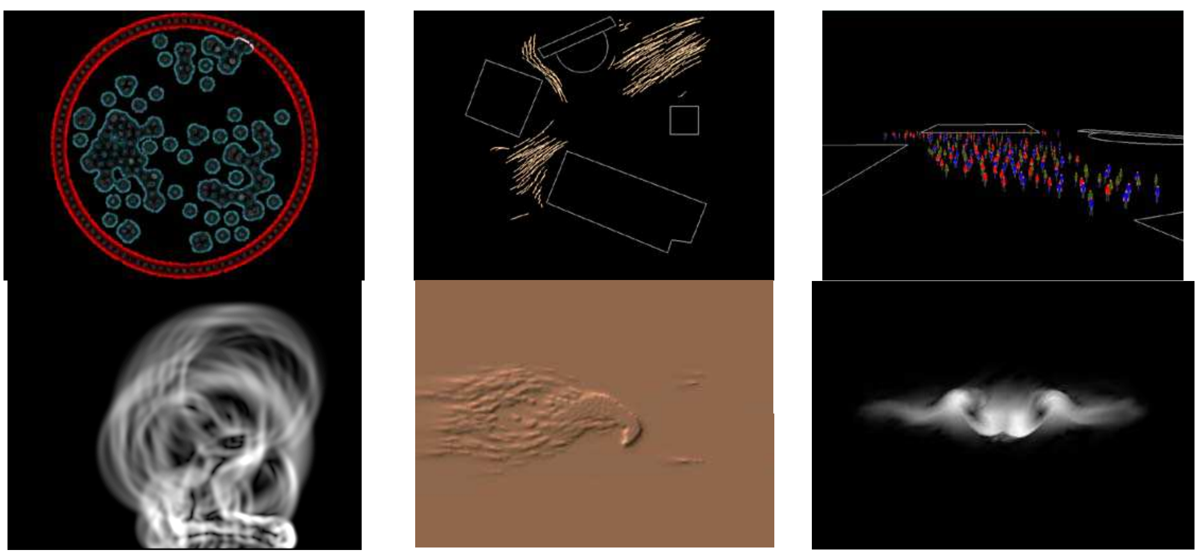

Fig.6 - Images from "Mémoires Vives" - A. Luciani 2001

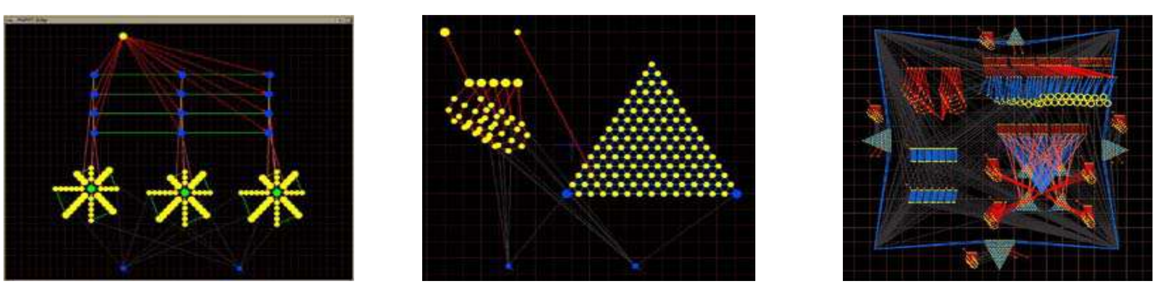

Fig.7 - GENESIS models for "pico..TERA" - C. Cadoz 2001